PROBLEMS OF AUTOMATION AND MECHANIZATION

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CONTROL OF THE THERMAL CONDITIONS OF A TANK FURNACE BASED ON PRODUCED GLASS HOMOGENEITY

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Mathematical models are constructed to describe the dependences of homogeneity, defects, and specific heat consumption on melting conditions. The efficiency of using daily variations in glass homogeneity and density to control the thermal regime of a tank glass-melting furnace is demonstrated.

The stability of the glass-melting process in sheet-glass production is monitored by daily measurements of density. The homogeneity of glass is monitored less frequently, once a week. The efficiency of controlling the temperature conditions in a tank glass-melting furnace based on produced glass density was discussed in [1].

The present paper considers the control of the thermal conditions of a tank furnace based on produced glass homogeneity. Comparative data are given for the control algorithms based on glass density and homogeneity and the manual control of the melting process. The efficiency of the algorithms is estimated using experimental data collected on an LPS-5000 production line over a year of continuous operation.

To implement a method for compensatory control of the furnace operation, mathematical models were constructed, which describe the dependence of the average daily parameters of the produced glass on the melting conditions:

glass homogeneity

$$\begin{aligned} Hom(t) = {} & b_0 + b_1\theta_{\mathrm{gm}_1}(t-9) - b_2\theta_{\mathrm{gm}_2}(t-9) \\ & + b_3\theta_{\mathrm{gm}_3}(t-9) - b_4H(t-5) \\ & + b_5w_{\mathrm{Fe_2O_3}}(t) + b_6\Delta G_{\mathrm{sh}}(t-7); \end{aligned}$$

glass cord

$$\begin{aligned} Cor(t) = {} & s_0 - s_1\theta_{\mathrm{gm}_1}(t-1) - s_2\theta_{\mathrm{gm}_2}(t-2) \\ & + s_3\mathrm{R}(t) + s_4G_{\mathrm{sh}}(t-2) + s_5w_{\mathrm{Fe_2O_3}}(t); \end{aligned}$$

bubble content in glass

$$B(t) = p_0 - p_2\theta_{\mathrm{gm}_2}(t) + p_3\theta_{\mathrm{gm}_3}(t) + p_4\mathrm{R}(t);$$

specific heat consumption in glass melting

$$g_{\mathrm{h}} = q_0 - q_1G_{\mathrm{sh}}(t) + q_2\theta_{\mathrm{gm}_2}(t) - q_3H(t),$$

where *Hom* is glass homogeneity, °C; t is current time, days; θ_{gm_1}, θ_{gm_2}, θ_{gm_3} is the glass melting temperature indicated by the bottom thermocouples located along the axes of the first, second, and seventh burners, °C; H is the insoluble sediment content, %; $w_{\mathrm{Fe_2O_3}}$ is the weight content of ferric oxides in the glass, %; ΔG_{sh} is the daily variation in the glass output per shift, kg; *Cor* is the glass cord level determined by comparison with eight samples; R is the redox number; G_{sh} is the glass output per shift, kg; B is the number of bubbles, units; g_{h} is the specific heat consumption, kcal/kg.

The required precision of description of variables was provided by periodic refining of the model coefficients using one-step adaptation algorithms. The permissible absolute error for the models was set equal to 0.1°C for homogeneity, 0.05 for cord level, 1 bubble for bubble count, and 40 kcal/kg for specific heat consumption.

The problem of controlling the furnace based on glass homogeneity is formulated as a one-step problem of making decisions to correct the furnace thermal conditions once a day. The permissible values for the limits in daily variations in glass homogeneity, the maximum permissible cord and bubble content, and the value of variations in the glass-melting temperature conditions in introducing corrections were written using a penalty function:

$$\begin{aligned} M(t) = {} & 0.015(|\min(7.5 - |\theta_{\mathrm{gm}_1}(t-1) \\ & - \theta_{\mathrm{gm}_1}(t)|,0)| + 3.75|\min(2 - |\theta_{\mathrm{gm}_2}(t-1) \\ & - \theta_{\mathrm{gm}_2}(t)|,0)| + 3.41|\min(2.2 - |\theta_{\mathrm{cm}_3}(t-1) \\ & - \theta_{\mathrm{gm}_3}(t)|,0)|) + 0.046(|\min(9 - B(t),0)| \\ & + 6.43|\min(1.4 - Cor(t),0)|) + |\min(0.05 \\ & - |Hom(t-1) - |Hom(t)|,0)|. \end{aligned}$$

The optimum glass-melting temperature conditions were found from the condition of getting the minimum (zero) pen-

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TABLE 1

Control regime	Glass homogeneity, °C	Glass density, g/cm³	Cord level by samples	Number of bubbles, units	Optical distortion by Zebra method, deg	Specific heat consumption, kcal/kg
Manual control	2.32* / 0.16	2.4859 / 0.00064	1.33 / 0.24	8.2 / 2.4	48.4 / 7.9	2027.7
Control by glass homogeneity	2.19 / 0.05	2.4850 / 0.00021	1.37 / 0.11	6.4 / 0.96	46.5 / 6.5	2035.8
Control by glass density	2.19 / 0.05	2.4851 / 0.00024	1.48 / 0.11	7.7 / 0.9	7.7 / 6.4	2022.3

* Above the line — mean; below the line — mean quadratic deviation of the variable.

alty $M(t)$ for failure to meet the preset conditions. The search was carried out using the method of coordinate descent along the regime variables θ_{gm_1}, θ_{gm_2}, and θ_{gm_3}.

The efficiency of control algorithms was estimated by simulation modeling of the system using the software complex "Glass Production Technologist" [2], which makes it possible to correlate the modeling results with the data obtained in manual control of the furnace for similar operating conditions of the production line. The comparative results of control-algorithm modeling and manual control of the glass-melting process on an LPS line during the year are given in Table 1.

In controlling the furnace thermal conditions on the basis of daily variation in homogeneity and density, the density and homogeneity of the produced glass is stabilized compared to the manual control of the glass-melting process. The quality of the glass is improved due to the decreased mean quadratic deviation (2.2 times for cord level, 2.5 – 2.8 times for bubble content, and 1.2 times for optical distortions). At the same time, the bubble content in the produced glass band decreases by 22%. The difference in specific heat consumption in glass melting does not exceed 0.4%, which is within the modeling error, and this difference can be neglected.

The imitation modeling confirmed the equal efficiency of using homogeneity and density of produced glass to control the glass-melting process and determine the controlling actions intended to correct the thermal conditions of a glass-melting furnace in sheet-glass production.

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